



Selection of waste plastics for incorporation in agro-waste as sustainable building construction materials concerning circular economy: an integrated MCDM approach

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Abstract

The recycling of waste plastics has been recognized as an enticing approach towards the circular economy. The post-consumer plastic products with the incorporation of agro-industrial waste were utilized for the advancement of value-added composites for structural applications. The properties of the composites, namely density, water absorption, compressive strength, flexural strength and abrasive wear, were found to influence by the type of plastics which increases the complexity in the material selection. The research proposed an integrated Analytic Hierarchy Process—Weighted Aggregated Sum Product Assessment (AHP-WASPAS) mathematical model for ranking the composites. The research identified the amalgamation of 15 wt % of rice husk ash and 15 wt % of sand with 70 wt % of polyetheretherketone (PEEK) as a suitable composite for structural applications having minimum abrasive wear and water absorption of 0.0937 cm³ and 0.05059%, respectively. The maximum density, flexural strength and compressive strength were found to be 1.5116 g/cm³, 6.564 MPa and 32.7933 MPa, respectively. Spearman's rank correlation coefficient (SRCC) between the proposed AHP-WASPAS model, and AHP-Weighted Sum Method (WSM), AHP-Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), AHP-Complex Proportional Assessment (COPRAS), AHP-Multi-Objective Optimization on the basis of Ratio Analysis (MOORA), AHP-Multi-Attributive Border Approximation area Comparison (MABAC) and AHP-Additive Ratio Assessment (ARAS) was in the range of 0.7854–1. The sensitivity analyses have observed that the ranking is influenced by the changes in criteria weights includes, density, water absorption, compressive strength, flexural strength and abrasive wear. Moreover, the rankings are unaffected by the parameter lambda (λ) in the WASPAS method. The research has verified the feasibility of waste plastics and agro-industrial waste as innovative materials. Moreover, the proposed mathematical model is reliable and enhances the material selection process in the development of composites.

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Graphical abstract



Keywords Circular economy · Characterizations · Sustainable composites · Materials selection · Multi-criteria decision-making

Introduction

The argument on "circular economy (CE)", as a novel paradigm contradictory to the typical "linear economy", has been developed to cope with the declining natural resources and wastes produced by the various economic activities (Ruokamo et al. 2023). Consequently, despite of a limited theoretical and empirical studies, these issues have gained a great research interest. The researchers are concerned about the integration of CE into a linear economy and the evaluation of the implications of CE policies. CE plays an important role in achieving sustainability; therefore, several countries around the globe have adopted the concept of CE as a pillar of sustainable development (Elschami and Kümmerer 2020). Nowadays, researchers are striving for an interrelationship between the sustainability and CE, and the methods to encourage the crucial sectors for the implementation of CE.

Recycling is one of the functional paradigms, and the operational strategy of CE has been promoted to reduce the consumption of resources and is recognized as a media of energy generation by utilizing waste materials (Zorpas 2020). In the context of polymeric composites, this system has been modified to improve the performance and quality of the developed products. The excellent workability of the polymer-based materials has provided momentum in CE (Ribul et al. 2021). The ability to transform a product's tangible behaviour into a product with optimum quality can revolutionize the design of a product.

The wide usage of plastic in different fields has exponentially increased the generation of plastic products, whereas the low-biodegradability of plastic products generates a significant

amount of plastic trash, which is endangering the globe (Soni et al. 2022b). The global manufacturing of plastic products is reported to increase from 1.5 to 335 million tons between the years 1950 and 2016. Moreover, the utilization of plastic products is estimated to be 297.5 million tons for the year 2015. The global production of plastic products is progressively increasing at a rate of 8 billion metric tons per year. It is anticipated that by the year 2025, about 12 billion tons of plastic waste will be dumped in landfills. The predicted annual production of plastic garbage is 300 million metric tons (Verma et al. 2016). The United Nation (UN) has estimated the generation of plastic waste to be 400 million tons by the year 2020, which is further projected to be 840 million tons for the year 2035, and 1600 million tons for the year 2050 (Ali et al. 2021). According to a study conducted by the Environmental Protection Agency (EPA), out of the total generated plastic waste only about 7% gets recycled, while the remaining is dumped into the environment unanswered (Groh et al. 2019).

The discarded plastics on entering the natural environment are migrated through a different medium and negatively affect the natural environment and the health of wildlife and humans. When plastic debris reaches the oceans, it deteriorates the environment, economy and aesthetics (Jambeck et al. 2018). The recycling of waste plastics offers a sustainable approach to the effective management of plastic waste. Additionally, reuse, cycling and recycling of plastic wastes are more efficient when compared to dumping, landfilling and incineration. Plastics can work as a vector for organic pollutants, micro-organisms and heavy metals. Moreover, plastic waste releases several harmful chemicals into the environment therefore, is a source of toxic chemicals (Chen et al. 2019). The disposal of plastic waste has a

detrimental effect on human health through direct inhalation or indirect digestion. Moreover, several biological reactions such as oxidative stress, inflammation, necrosis, etc. are caused due to the persistence of microplastics which may severely damage the human tissues. The incineration of waste plastics releases several harmful products into the environment including toxic gases, particulates, volatile compounds, etc. (do Prado Leite et al. 2022). Plastic wastes can contaminate the quality of soil either by setting over the surface or penetrating through the layers. The formation of microplastics due to the fragmentation of plastic wastes affects the microbial activity of the soil and deteriorates the soil quality thus affecting the productivity of crops. Moreover, the microplastics enter into the soil layers and affect the quality of the groundwater. The plastic wastes reach the oceans and marine bodies and disturb the microbial activities of the marine creature which increases the sea pollution and affects the lives of aquatic organisms (Zhang et al. 2022).

Rice is a primary crop across numerous countries of the globe. The worldwide production of rice is reported to be 499.31 million metric tons for the year 2020. The milling of each kg of rice generates nearly 0.28 kg of rice husk. Rice husk is a by-product produced during the milling of rice. A fraction of the rice husk is utilized as fuel in the parboiling process, while the remaining is treated as waste. Rice husk ash (RHA) produced during burning of rice husk is dumped in landfill which affects the environmental condition besides imposing a higher cost on the production of rice (Foo and Hameed 2009). Due to the scarcity of available land, effective treatment of the generated RHA is considered a global challenge (Soni et al. 2022d).

The low-cost, environment-friendly, lightweight, improved workability and life cycle has been gained the importance of sustainable composite materials. Regardless of the development, the ongoing mitigating strategy for solid waste through the exploration of innovative and sustainable composites is crucial for the enhancement of the material system (Mohanty et al. 2018). The composites developed by recycling and using sustainable resources have been embraced as an essential component of CE for the coming generations. Sustainable composites belong to the category of materials which offers great environmental value with little or no involvement of cost. These composites can successfully replace conventional composite materials and are potent in overcoming the issues arising due to the mismanagement of plastic wastes (Sanjay et al. 2019). The recycling of post-consumer plastic products for the development of novel and value-added composite materials for building construction is a viable approach to overcome the burden of plastic waste from the earth besides fulfilling the requirement of shelter for the humans (Taiwo et al. 2022). The emergence of sustainability in different sectors could fulfil the ever-increasing demands for fresh raw materials (Elavarasan et al. 2022).

Material selection is a decisive phase in the design and manufacturing of any product. The proper selection of material

enhances the performance, reduces the failures and functional energy requirement, and therefore enhances the overall life cycle of the product (Soni et al. 2022a). The wide variety of materials with different characteristics, benefits and limitations makes the identification of an optimal selection of materials a cumbersome and time-consuming process. While selecting a material for an engineering application, a designer considers some attributes and available choices based on the functional requirements. There exists a complex interaction between the characteristics of the available materials and considered criteria; this makes material selection a complex process. The selection of proper materials under conflicting criteria can be viewed as a multi-criteria decision-making (MCDM) problem. The selection of suitable material by trial and error methods will consume a lot of time and resources. Thus, necessitates the development of a logical, systematic and reliable approach for material selection. The developed mathematical-based MCDM techniques have proved their success in the materials selection process for a diverse engineering field for different applications.

Analytic Hierarchy Process (AHP) is a recognized MCDM method to deal the real-world complications in material selection. The implementation of AHP for the assessment of floor tiles system in the view of sustainability revealed that the framework for decision-making is consistent with practices of sustainable construction. Being conceptually simple and popular, the method is incapable of handling the inherent vagueness and ambiguity in decision-makings.

The weighted sum method (WSM) is a simple MCDM approach where the alternatives are ranked according to their score obtained by the summation of their corresponding weights. Furthermore, the weighted product method (WPM) is an efficient approach for decision-making in a multi-criteria situation. The method used simple mathematics for the calculation of the performance scores. Weighted Aggregated Sum Product Assessment (WASPAS) method is the hybridization of WSM and WPM techniques which ranks the alternatives according to the collective scores resulting from the WSM and WPM (Turskis et al. 2019). The method is based on the theory of utility which depends on the additive and multiplicative utility functions. The technique is gaining the interest of researchers. The technique is efficient and effective for ranking the alternatives and gives consistent results with a minimum rank reversal.

The alarming rate of plastics waste generation, the necessity of building construction materials to meet the requirement of shelters for an ever-increasing population and concerns for the environmental condition have motivated the world towards the utilization of waste plastics for sustainable building construction materials. The workability of materials has shown their dependency on the compositions but the behaviour of a material for a given property is irregular which increases the complexity of the material selection

process. The available MCDM has proved their success in the advancement of different engineering materials for wide applications.

Cicek et al. have presented an integrated decision aid (IDEA) approach through the combination of structural and evaluation phases to approve the methodology against a case problem (Cicek et al. 2010). Milani et al. have carried out a comparison between vector normalization and four linear normalization methods for the identification of suitable materials for industrial application (Milani et al. 2005). Zarandi et al. have utilized life cycle engineering (LCE) for material selection of an engineering material (Zarandi et al. 2011). Bovea and Gallardo have proposed a Life Cycle Impact Assessment (LCIA) approach for the material selection of a component (Bovea and Gallardo 2006). Sapuan has introduced a knowledge-based method for engineering devices (Sapuan 2001). But these methodologies fail to give reliable results and require a lot of knowledge-based and intelligent database systems. Kumar et al. have successfully applied Vlekraterijumsko KOMPromisno Rangiranje (VIKOR) to identify an appropriate material for an energy storage system (Kumar et al. 2022a). Yadav et al. have applied the Analytic Hierarchy Process-Technique for Order Performance by Similarity to the Ideal Solution (AHP-TOPSIS) for the selection of a suitable dental composite by considering different criteria (Yadav and Lee 2022). The academics have applied MCDM techniques to select a material for automobile rooftops and obtained a reduction in the temperature of about 9 °C through the identified material (Nicolalde et al. 2022). The modified version of ELimination and Choice Expressing Reality (ELECTRA) as Fematean fuzzy ELECTRA I has been successfully applied for the selection of biomaterials for human body (Kirişçi et al. 2022). A linguistic assessment-based TOPSIS method was applied in the identification of construction materials (Chen et al. 2021). Aladdin et al. have applied a hybridized AHP-ELECTRA method for sugar fibre-reinforced composites (Alaaeddin et al. 2019). Furthermore, the different MCDMs were applied for an optimum yield of the product during pyrolysis through the identification of a suitable material. The study has identified that the sugarcane bagasse results in maximum yield among the given set of alternatives (Madhu et al. 2020). The design of composite materials under the condition of variable loads was carried out by using a data-driven model (Kumar et al. 2022b). The researcher has identified aluminium alloy as an appropriate material for blades of turbine blade by using AHP-TOPSIS (Okokpujie et al. 2020). The study for a suitable material for brake booster was carried out through a combined Analytic Hierarchy Process–Multi-Objective Optimization on the basis of Ratio Analysis (AHP-MOORA) approach has identified the composites incorporated with 35% of fibres with 65% of PET as a suitable materials for brake booster (Moradian et al. 2019). Moreover, the AHP-MOORA was applied for polymeric composites for floor tiles (Soni et al. 2022c). An hybrid MCDM method was applied for the selection of a suitable composite material (Soni et al. 2022a).

The study of rank reversal problems in material selection was carried out by using three well-known MCDM techniques (Mousavi-Nasab and Sotoudeh-Anvari 2018). AHP was successfully applied for the material selection of a piston (Lohakare et al. 2022). Moreover, the selection of suitable materials for connecting rods has been carried out (Sen et al. 2016). The research has been performed for the identification of sustainable building materials through hybrid MCDM techniques and the result is validated through feedback (Govindan et al. 2016). Stepwise Weight Assessment Ratio Analysis-Combinative Distance-based ASsesment (SWARA-CODAS) was applied for the material selection for the construction of dam considering the technical and economic aspects (Ijadi Maghsoodi et al. 2019). Additionally, the Stepwise Weight Assessment Ratio Analysis-Combined Compromise Solution (SWARA-CoCoSo) was proposed to identify the barriers in the manufacturing process (Cui et al. 2021). The successful implementation of the SWARA-VIKOR in the lean manufacturing was demonstrated (Yücenur and Şenol 2021). The comparison of the different MCDM approaches in materials selection of composites developed by recycling waste plastic was carried out (Emovon and Oghenyerovwho 2020). Zhang et al. have applied MCDM for the identification of suitable material for an engineering component (Zhang et al. 2020). Liao has proposed a fuzzy TOPSIS approach in two interval types which can be successfully applied to select suitable materials without any information about the material property (Liao 2015). Mansor et al. have applied AHP in fibre-reinforced composites for automobile vehicles (Mansor et al. 2013). Moreover, materials of a pipe for the sugar industry were selected (Anojkumar et al. 2014). The MCDM integrated with modelling techniques was applied for the material selection of building construction (Figueiredo et al. 2021).

The literature has shown the implementation of MCDM methods for the optimal choice of conventional materials for application in diverse engineering fields, and rare studies are concerned with sustainable composite materials. However, there is an absolute dearth of research on the material selection in the design of a sustainable composite for building construction applications. The authors believe that the establishment of mathematical-based MCDM models in material selection for sustainable composites under the considered set of alternatives and criteria is not yet reported in any of the literature. The aim of the research is to develop a simple mathematical model for material selection. However, the objective is to recycle waste plastics and rice husk ash for an innovative and sustainable material for structural applications.

Recycling waste plastics with the reinforcement of agrowaste for building construction materials is a sustainable approach to reduce the exhaustion of natural resources and energy requirements, besides improving the environmental conditions. In this view, polymer-based sustainable composites are developed by recycling eight (08) different types

of waste plastics with the incorporation of RHA and silica sand. Further, the examinations for the workability of the composites have revealed the dependency of properties on compositions; however, the behaviours of the composites for the tested properties vary irregularly. The research proposes an integrated AHP-WASPAS mathematical model for the material selection of composite materials. The alternatives are ranked by using the proposed integrated AHP-WASPAS approach. The reliability of the model is confirmed by performing comparative analysis of ranking results of the proposed model with other MCDM techniques and sensitivity analyses for the criteria weights and the parameter λ in the WASPAS method.

The developed composites are intended for floor tiles, pavements, paving blocks, etc., in the non-traffic area of public places. Moreover, the composites can be successfully used in structural applications where the consideration for compressive and bending loads are of prime importance. The excellent water-resisting quality enhances the durability of the composites during their application.

The introduction of innovative and novel materials by using different thermoplastics and agro-waste is a viable approach to overcome the issues associated due to the mismanagement of plastics and argo-industrial wastes. In the context of the material selection, the novelty can be identified by the proposed AHP-WASPAS model because of the integration of two simple and effective mathematical techniques with fewer mathematical calculations. The comparative studies and sensitivity analyses for criteria weight and parameters involved in the methods for the verification reliability is an another of the proposed mathematical model.

The research provides a simple and reliable mathematical approach for ranking alternatives and identification of a suitable composition. The research contributes to overcome the environmental issues besides providing alternative materials for building construction. The research is advantageous for the researcher engaged in the area of sustainability. The research can assist the industries involved in the manufacturing of composites and therefore is potent to increase the productivity of the manufacturing industries. The research is pivotal for the advancement of CE and the attainment of sustainable goals.

The study is organized as follows: (i) the material, methods and characterization techniques of the composites are discussed in Sect. "Experimental". (ii) Sect. "Proposed AHP-WASPAS model" provides the basic steps of the AHP and WASPAS methods (iii) Section "Application of the AHP-WASPAS model" provides the application proposed approach. (iv) The results and discussions are summarized in Sect. "Results and discussions" (v). Lastly, in Sect. "Conclusions and future scope", the conclusions are derived, and the future scope of the research is reported.

Experimental

This section gives the details of the raw materials, methods and procedures followed for the development of the composites. Moreover, the discussions of the characterization techniques are presented in this section.

Materials

The raw materials for the development of composites are mainly comprised of fillers and matrices. The function of the matrix is to hold the filler particles together and provide the desired shape to the composites while the fillers modify the properties of the filler-reinforced composites. In the present work, in total, eight (08) different types of waste plastics, namely, low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), polyvinyl chloride (PVC), polycarbonate (PC) and polyetheretherketone (PEEK) are taken as matrices, while RHA and sand are taken as the fillers. The properties of the waste plastics are furnished in Table 1. The chemical constituents and physical properties of RHA are furnished in Table 2. The images of the materials are given in Fig. 1.

Methods

The composites are developed by following the steps given in Fig. 2. The post-consumer plastic products are collected from waste collection points. The collected waste plastics are sorted, cut to open and cleaned with water for the removal of contaminations. The plastics are then dried in ambient conditions to ensure that moisture is completely removed. The plastics are shredded into smaller pieces and mixed as per the compositions given in Table 3. The mixture is heated up to the melting point of plastic and mixed properly to obtain a homogenous mixture. The composites are fabricated through the hydro-static compaction method under a compressive load of 20.7 MPa. The samples are then allowed to cool at ambient conditions, and any burrs and fins are removed. The samples are then prepared to the required dimensions for different characterizations. Figure 3 gives the images of the developed composite samples.

Characterization of composites

The performance of the developed floor tile samples is verified by conducting different characterizations. The density, water absorption, compressive strength, flexural strength and abrasive wear are evaluated according to the standard procedure, which can be considered as performance-defining criteria (PDC) for the identification of a suitable composite.

Table 1 Properties of waste plastics (Desideriy and Lanotte 2022)

Type of plastics	Property					
	Tensile strength (MPa)	Notch impact strength (kJ/m ²)	Coefficient of thermal expansion	Melting point (°C)	Density (g/cm ³)	
LDPE	0.2–0.4	No break	100–220 × 10 ⁻⁶	65	0.917–0.930	
HDPE	0.2–0.4	No break	100–220 × 10 ⁻⁶	75	0.944–0.965	
PET	2.5	1.5–3.5	70 × 10 ⁻⁶	70	1.37	
PP	0.5	1.5	70 × 10 ⁻⁶	200	1.34	
PS	2.2–2.7	10–20	80 × 10 ⁻⁶	60–80	1.03–1.06	
PVC	2.60	2.0–45	80 × 10 ⁻⁶	60	1.38	
PC	70–80	60–80	65 × 10 ⁻⁶	125	1.20	
PEEK	97–100	6.1–7.5	47 × 10 ⁻⁶	250	1.28–1.32	

Density and water absorption are important physical properties for structural applications. The density (ρ) of the composite determines the fraction of constituents and the void content of the composite. It is determined by following the ASTM D3171 standard test procedure for the density of composite where the sample is made to immerse in water which experiences an upward thrust equivalent to the weight of the liquid displaced. The weight is measured by employing a laboratory Mettler Teledo balance of JL6001GE/A, having an accuracy of 0.1 g. The density is calculated by using the given Eq. (1)

$$\rho = \frac{A}{A - B} (\rho_o - \rho_L) + \rho_L \quad (1)$$

where ρ = density of the sample

A = weight of sample in air

B = weight of sample in liquid ρ_o = density of the liquid ρ_L = density of the air

Water absorption denotes the moisture content and internal porosity of a composite. The evaluation of water absorption is essential to examine the suitability of the composites at ambient conditions. The water absorption (W_a) test is conducted according to the ASTM C373 standard test for water absorption. Here, the sample is immersed in distilled water for 24 h and is weighted which gives the wet weight of the sample. The sample is then dried completely in an oven at elevated temperatures and is reweighted by an accurate weighing instrument which gives the dry weight of the sample. The waste absorption (%) is calculated by using Eq. (2).

$$\text{Water absorption(\%)} = \frac{\text{Wet weight of the sample} - \text{dry weight of the sample}}{\text{Dry weight of the sample}} \times 100 \quad (2)$$

To examine the response of a composite against an external load, the evaluations of the compressive (C_s) and flexural strength (F_s) are performed. The compressive strength determines the strength of floor tiles under a compressive load and

is evaluated by employing a hydraulic compression testing machine (CTM) of model UTM-4000FPR having a 600 KN (shown in Fig. 4a) according to ASTM C648 standard test for compressive strength. The specimens are loaded gradually until a fracture is observed the maximum load is recorded. The compressive strength is calculated by the given Eq. (3)

$$C_s = \frac{P_c}{A_c} \quad (3)$$

where

C_s = compressive strength (N/mm²)

P_c = maximum load on the sample (N)

A_c = cross-sectional area (mm²)

The flexural strength denotes the strength of the floor tiles under a bending load which is evaluated by employing a hydraulic universal testing machine (UTM) of model HL59020 having a capacity of 600 KN (shown in Fig. 4b) according to the ASTM C1505 standard test for breaking strength of ceramic tile by using Eq. (4)

$$S = \frac{3WL}{2bt^2} \quad (4)$$

where S = flexural strength (N/m m²), W = maximum load (N), L = length in mm, b = width in mm, t = thickness in mm

The tribological performance as three-body abrasive wear is determined by using a dry abrasion tester TR-50 of Ducom India Pvt. Ltd. is schematically illustrated in Fig. 4c. The abrasive wear is evaluated as per the G65 standard test for dry abrasion. The volume loss (cm³) is calculated at a

load of 68 N under the sliding speed of 0.8980 m/s. The sample is held against a rotating rubber wheel by a sample holder provided at the end of the loading lever having a lever ratio of 2.3, and an initial load of 3.5 kgf, as shown

Table 2 Chemical constituents and physical properties of RHA

Chemical composition (%)		Physical property								
SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	LOI	Mean particle size	Specific gravity	Surface area (m ² /g)
87.30 (28–35 nm)	0.84 (1.5–1.9 μm)	0.73 (70–90 nm)	1.40 (50–70 nm)	0.57 (0.5–0.8 μm)	1.12 (0.8–0.9 μm)	3.68 (5.4–6.4 nm)	8.55 (0.92–1.0 μm)	6.27 μm	2.08 g/cm ³	36.47 m ² /g

in Fig. 4d. The load on the sample is calculated by using Eq. (5). The American Foundry Society (AFS 60) sand is used as an abrasive, which flows at a constant sand flow rate of 500 g/min during the test duration of 60 s. The loss in volume is calculated by using Eq. (6) gives the abrasive wear of the sample.

$$\text{Load on wheel} = (\text{dead weight} \times \text{lever ratio} + \text{initial load}) \tag{5}$$

$$\begin{aligned} &\text{Volume loss (cm}^3\text{)} \\ &= \frac{\text{Weight before test} - \text{Weight after test (gms)}}{\text{Density} \left(\frac{\text{gm}}{\text{cm}^3} \right)} \end{aligned} \tag{6}$$

Properties of composites

The resulting values for the evaluated properties are listed in Table 4. The density of the composites is in the range of 1.07051–1.9833 (g/cm³). The potted values of the density in Fig. 5 show that the density of the composites varies irregularly with composition. The minimum density is observed for LD70R15S15, while the composite PC70R15S15 gives the maximum density. The density of the composites increases with the density of the plastic; therefore, the density increases to 1.676 g/cm³ for the composite HD70R15S15 which further decreases for PP70R15S15. The composite PC70R15S15 results in an optimum density due to the good density of the polycarbonate with fewer formations of voids. It is observed that the density of the composites PS70R15S15 is approximately equal to the PP70R15S15 because of the typical characteristics of the material. It is inferred from the results of density that the density of the composites is influenced by the density of the matrix as well the distributions of the reinforcements. Figure 6 gives the plot for the water absorption of the floor tile samples. The water absorption varies from 0.03095 to 0.17896% with maximum value for the composites HD70R15S15. The composite LD70R15S15 attains a minimum water absorption of 0.0467%, while the composites HD70R15S15 show maximum water absorption. The presence of voids at the surface and internal connectivity between the internal porosity and surface pores determines the water absorption of a composite. The developed samples show a good response for water absorption due to less porosity and good density. Moreover, it is observed that for the developed composites, the water absorption is less than 5%, therefore, verifying the suitability of the composites as floor tiles in ambient conditions of wet, dry or humid. The plot for the mechanical strength given in Fig. 7 shows that the maximum value of compressive strength and flexural strength is obtained to be 32.7933 and 6.564 (MPa), respectively, for the composite PEEK70R15S15. At the same time, the minimum

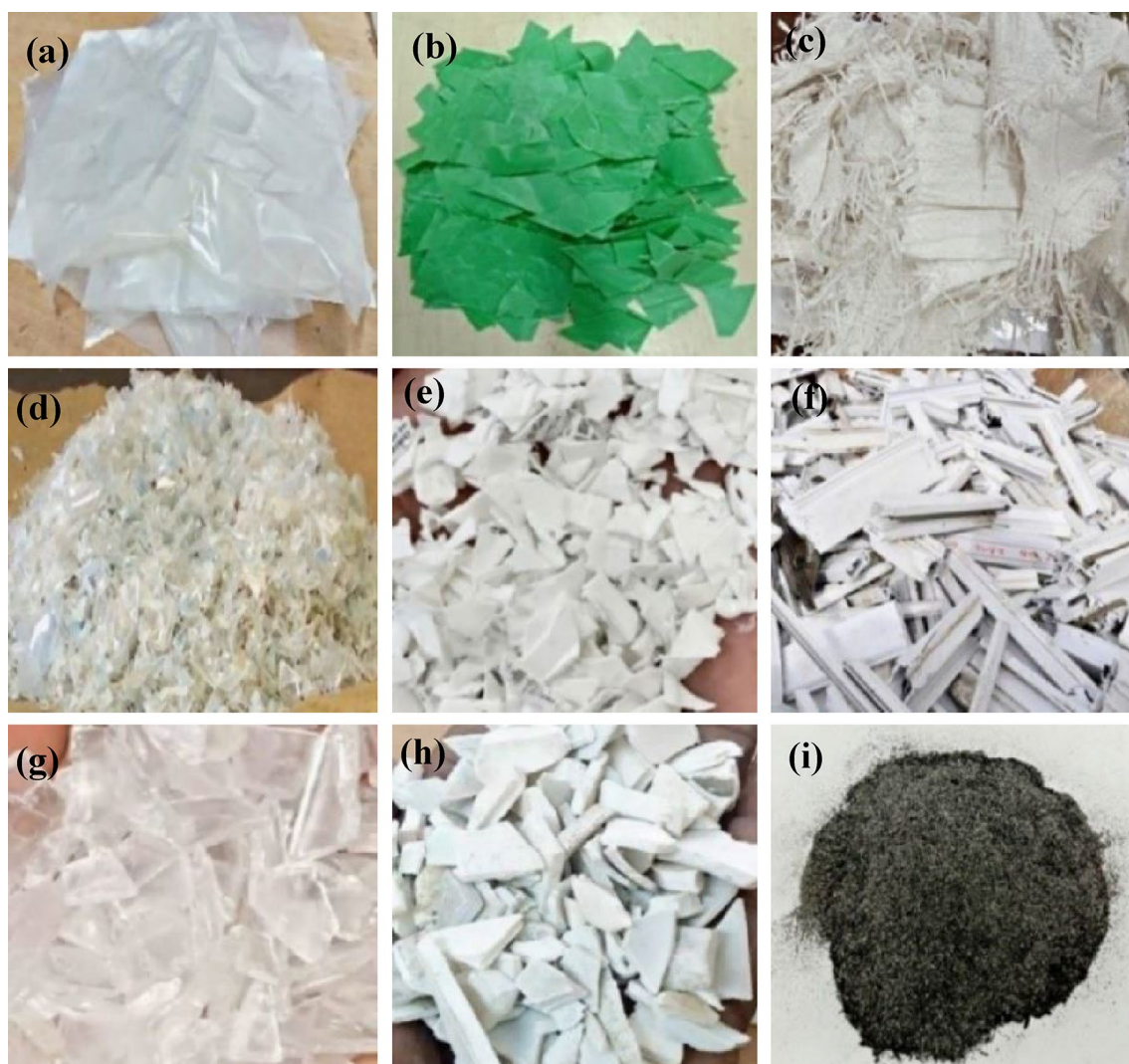


Fig. 1 Images of raw materials **a** LDPE **b** HDPE **c** PP **d** PET **e** PS **f** PVC **g** PC **h** PEEK **i** RHA



Fig. 2 Process flowchart for the development of samples

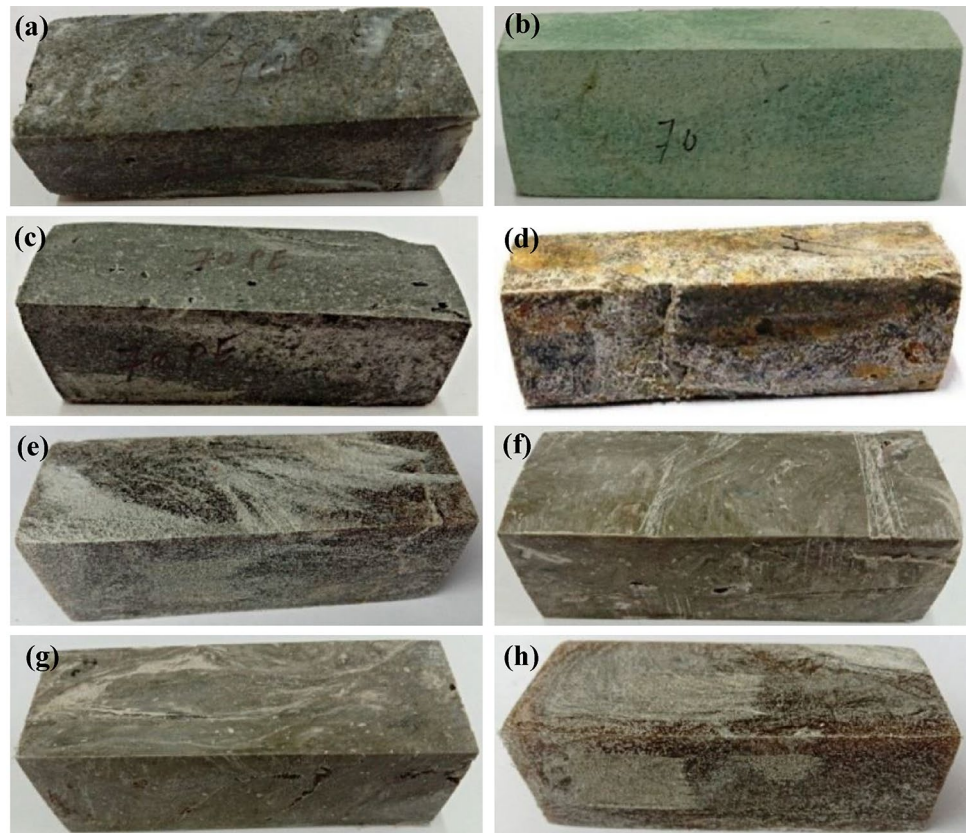
value for the compressive strength and flexural strength is obtained to be 7.5015 and 1.07269 (MPa), respectively, for the composite LD70R15S15. Moreover, an irregular behaviour for the mechanical strength of the matrix is observed. Moreover, the composites PP70R15S15, PET70R15S15, PVC70R15S15 and PEEK15S15 possess higher comparatively higher values of mechanical strength than other samples. The complete encapsulation of RHA and sand particles with sufficient strength of the matrix provide good mechanical strength to the composite. The fractions of fillers and matrix are also

responsible factors for determining the mechanical strength of the composites. The response for the mechanical strength of the composites correlates with the properties of the matrix and with the physical characteristics of the composites. The plot for the abrasive wear given in Fig. 8 shows the composite PET70R15S15 obtained a minimum volume loss of 0.03095 cm^3 . Whereas the maximum abrasive wear is obtained to 0.17896 cm^3 for the composites HD70R15S15 due to the low elasticity of HDPE. The results of the abrasion wear revealed that the wear performance depends on the characteristics of the

Table 3 Raw materials for the development of composites

S. No.	Alternatives	Sample designation	Wt % of raw materials										
			LDPE	HDPE	PP	PET	PS	PVC	PC	PEEK	RHA	Sand	
1	A1	LD70R15S15	70	–	–	–	–	–	–	–	–	15	15
2	A2	HD70R15S15	–	70	–	–	–	–	–	–	–	15	15
3	A3	PP70R15S15	–	–	70	–	–	–	–	–	–	15	15
4	A4	PET70R15S15	–	–	–	70	–	–	–	–	–	15	15
5	A5	PS70R15S15	–	–	–	–	70	–	–	–	–	15	15
6	A6	PVC70R15S15	–	–	–	–	–	70	–	–	–	15	15
7	A7	PC70R15S15	–	–	–	–	–	–	70	–	–	15	15
8	A8	PEEK70R15S15	–	–	–	–	–	–	–	70	–	15	15

Fig. 3 Images of the samples **a** LD70R15S15 **b** HD70R15S15 **c** PP70R15S15 **d** PET70R15S15 **e** PS70R15S15 **f** PVC70R15S15 **g** PC70R15S15 **h** PEEK70R15S15



matrix. Comparatively higher abrasive wear for the composites HD70R15S15 and PVC70R15S15 as compared to other composites is due to less elasticity possessed by HDPE and PVC. Conversely, the composites LD70R15S15, PET70R15S15 and PEEK70R15S15 show a better response to the abrasive wear due to sufficient elasticity of LDPE, PET and PEEK. The interactions of the encountering forces with the material characteristic and response of materials under the test conditions make the abrasive wear behaviour a complex process, and therefore an invariability abrasive wear is observed.

The comparative analysis of the characterization techniques shows that the properties of the composites vary considerably with compositions. Moreover, the behaviours of

the composites for the considered properties are irregular, therefore, making the identification of a suitable composition a difficult task. Thus, there arises a need for a reliable MCDM technique for the selection of raw materials as compositions and ranking of the alternatives.

Proposed AHP-WASPAS model

In this section, the proposed AHP-WASPAS model is discussed. The details of the AHP and WASPAS techniques and the steps required for ranking the alternatives by using AHP and WASPAS are provided.

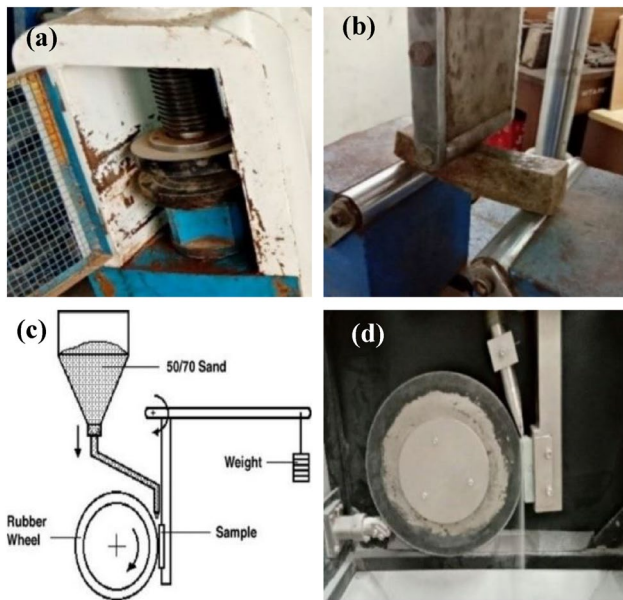


Fig. 4 Image of **a** CTM **b** UTM **c** schematic diagram of dry abrasion tester **d** sample during abrasion test

Analytical hierarchy process (AHP)

AHP was introduced by Satty in 1970 and is one of the popular methods to deal with the complex problems of decision-making through simple mathematical calculations. The AHP mainly includes three components, namely, the goal or problem to solve, the available options or choices to attain the goals are termed alternatives and the criteria required for the evaluation of alternatives. AHP offers a logical framework for any decision-making problem by quantifying the value of alternatives and criteria. The AHP method starts with the description of alternatives, problems and criteria, then the priority among the criteria is established through the formulation of a pairwise matrix, and finally, checking the consistency.

The steps for AHP are given as follows:

Step 1: Construct a pairwise decision matrix $[p_{ij}]_{n \times n}$ based on Satty's nine-point scale (Ong et al. 2021) as given in Eq. 7. Here, each element p_{ij} elucidates the relative importance of criterion I relative to criterion j.

Table 4 Resulted in value for the tested properties

S. No.	Sample	Abrasive wear (cm ³)	Water absorption (%)	Density (g/cm ³)	Flexural strength (MPa)	Compressive strength (MPa)
1	LD70R15S15	0.04670	0.19960	1.07051	1.07269	7.5015
2	HD70R15S15	0.17896	0.052383	1.67632	1.68477	8.5327
3	PP70R15S15	0.07468	0.68434	1.33893	4.89543	24.7933
4	PET70R15S15	0.03095	0.0397	1.6151	5.96	20.81
5	PS70R15S15	0.06470	0.29960	1.7015	2.0276	15.467
6	PVC70R15S15	0.17698	0.082383	1.3626	4.9843	23.7241
7	PC70R15S15	0.08647	0.86434	1.9833	3.8477	17.2741
8	PEEK70R15S15	0.05059	0.0937	1.5116	6.564	32.7933

Fig. 5 Density of the composite samples

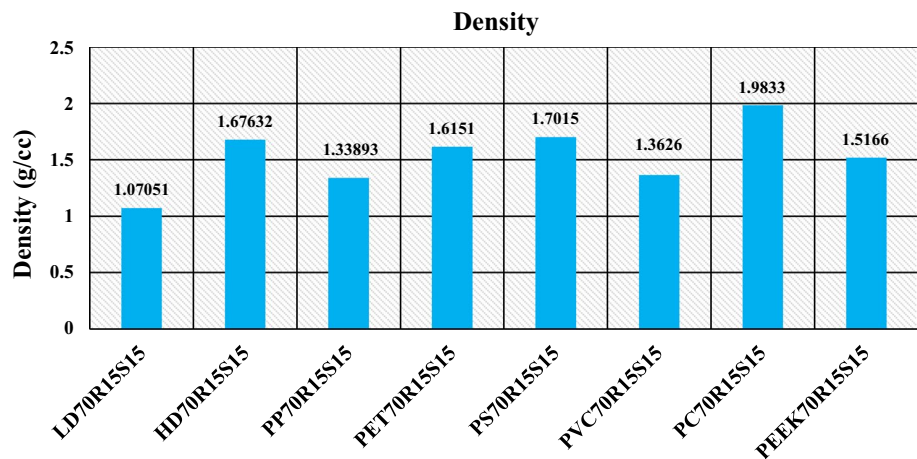


Fig. 6 Water absorption of the composite samples

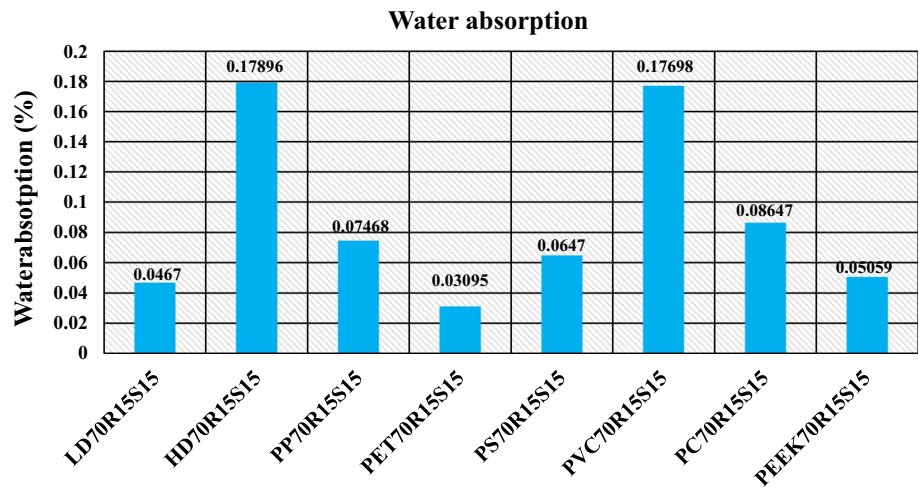


Fig. 7 Mechanical strength of the composite samples

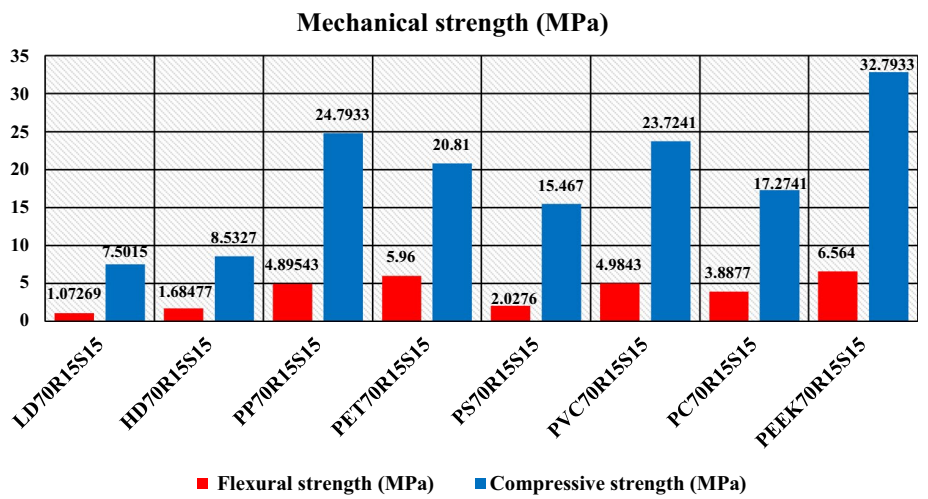
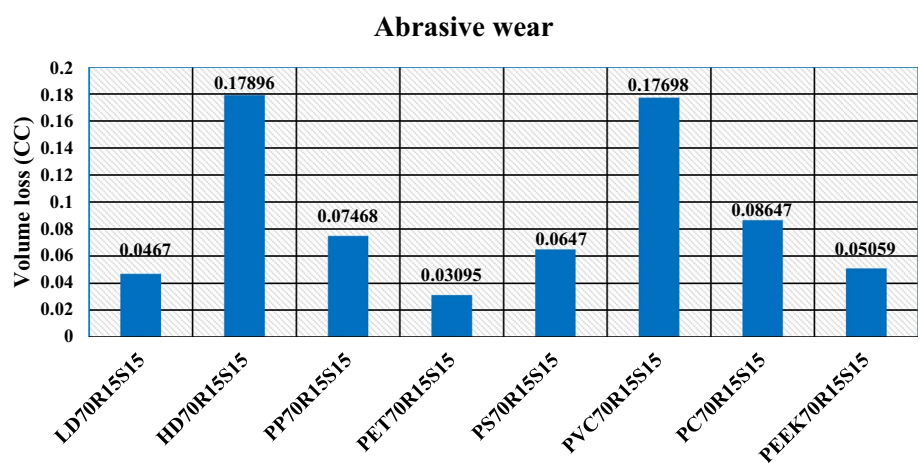


Fig. 8 Abrasive wear of the composite samples



$$P_{n \times n} = \begin{bmatrix} 1 & p_{12} & \dots & p_{1n} \\ p_{21} & 1 & \dots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{n1} & p_{n2} & \dots & p_{nn} \end{bmatrix} \tag{7}$$

Step 2: Compute the criteria weight vector by using Eq. 8.

$$V_i = A \cdot w_i \tag{8}$$

where, $w_i = \text{GeometricMean} / (\text{GeometricMean})_{avg}$ and, $\text{GeometricMean} = (p_{i1} * p_{i2} * p_{i3} * \dots * p_{in})^{\frac{1}{n}}$ for $i = 1, 2, 3, \dots, n$

Step 3: Obtain the value of the eigenvector (λ_i) by using Eq. 9.

$$\lambda_i = \frac{V_i}{w_i} \tag{9}$$

Step 4: Calculate the value of λ_{max} .

Step 5: Calculate the consistency index (CI) by using Eq. 10.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{10}$$

Step 6: Check the consistency by calculating the value of the consistency ratio (CR) by using Eq. 11.

$$CR = \frac{CI}{RI} < 0.1 \tag{11}$$

Weighted aggregated sum product assessment (WASPAS).

WASPAS was introduced by Zavadskas in 2012 and is an amalgamation of the WSM and WPM (Alinezhad and Khalili 2019). The method gives better accuracy in results as compared to WSM and WPM and is widely accepted as an effective decision-making tool.

Step 1: Obtain the decision matrix $D = [x_{ij}]_{m \times n}$ by using Eq. 12, where x_{ij} denotes the performance of i th alternative with respect to j th criteria.

$$D = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{12}$$

Step 2: Obtain a normalized decision matrix by using Eq. 13.

$$x_{ij}^* = \frac{x_{ij}}{\left[\sum_{i=1}^m x_{ij}^2 \right]^{\frac{1}{2}}}; (j = 1, 2, \dots, n) \tag{13}$$

Step 3: Calculate the weighted normalized matrix by using the weight vector of AHP.

Step 4: Obtain the relative importance of each alternative for the WSM and WPM method by using Eqs. 14 & 15, respectively.

$$Q_i^{(1)} = \sum_{j=1}^n \bar{x}_{ij} w_j \tag{14}$$

$$Q_i^{(2)} = \prod_{j=1}^n (\bar{x}_{ij})^{w_j} \tag{15}$$

where $\bar{x}_{ij} = \frac{x_{ij}}{\max_{i \in I} x_{ij}}$ (for beneficial criteria) = $\frac{\min_i x_{ij}}{x_{ij}}$ (for non-beneficial criteria)

Step 5: Compute the values of combined optimality by using Eq. 16.

$$Q_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} = 0.5 \sum_{j=1}^n \bar{x}_{ij} w_j + 0.5 \prod_{j=1}^n (\bar{x}_{ij})^{w_j} \tag{16}$$

Application of the AHP-WASPAS model

The proposed AHP-WASPAS model is applied for the materials selection of polymeric composites. Figure 9 gives the process-flow chart for ranking the eight (08) different alternatives as given in Table 3. Five (05) different attributes of the composites, such as abrasive wear (C1), water absorption (C2), density (C3), flexural strength (C4), and compressive strength (C5) given in Table 5, are taken as the Performance Determining Criteria (PDC) for rankings of composites. The hierarchy of the material selection process given in Fig. 10 shows the complexity involved in material selection. The pairwise decision matrix is fabricated by using the saaty's nine-point scale and is furnished in Table 6. The obtained pairwise decision matrix given in Table 7 shows the criteria weight for C1, C2, C3, C4, and C5 are 0.06, 0.02, 0.17, 0.29, and 0.46, respectively. The value of λ_{max} obtained from the maximum value of λ by using Eq. 9 is found to be 5.4416. The value of CI is obtained by using Eq. 10. The criteria weights obtained from the pairwise decision matrix are verified by calculating the value of CR, taking the random index (RI) of 1.12 from Table 8. The decision matrix is formulated in Table 9. The normalized decision matrix is calculated by using Eq. 13 and is given in Table 10. The weighted normalized decision matrix is obtained by multiplying the criteria weight with each element in the normalized decision matrix given in Table 11. The scores for the WSM and WPM methods are calculated by using Eqs. 14 and 15, respectively. The WASPAS score is obtained through the combination of WSM and WPM scores by using Eq. 16. The ranking of

Fig. 9 Algorithm of the proposed AHP-WASPAS model

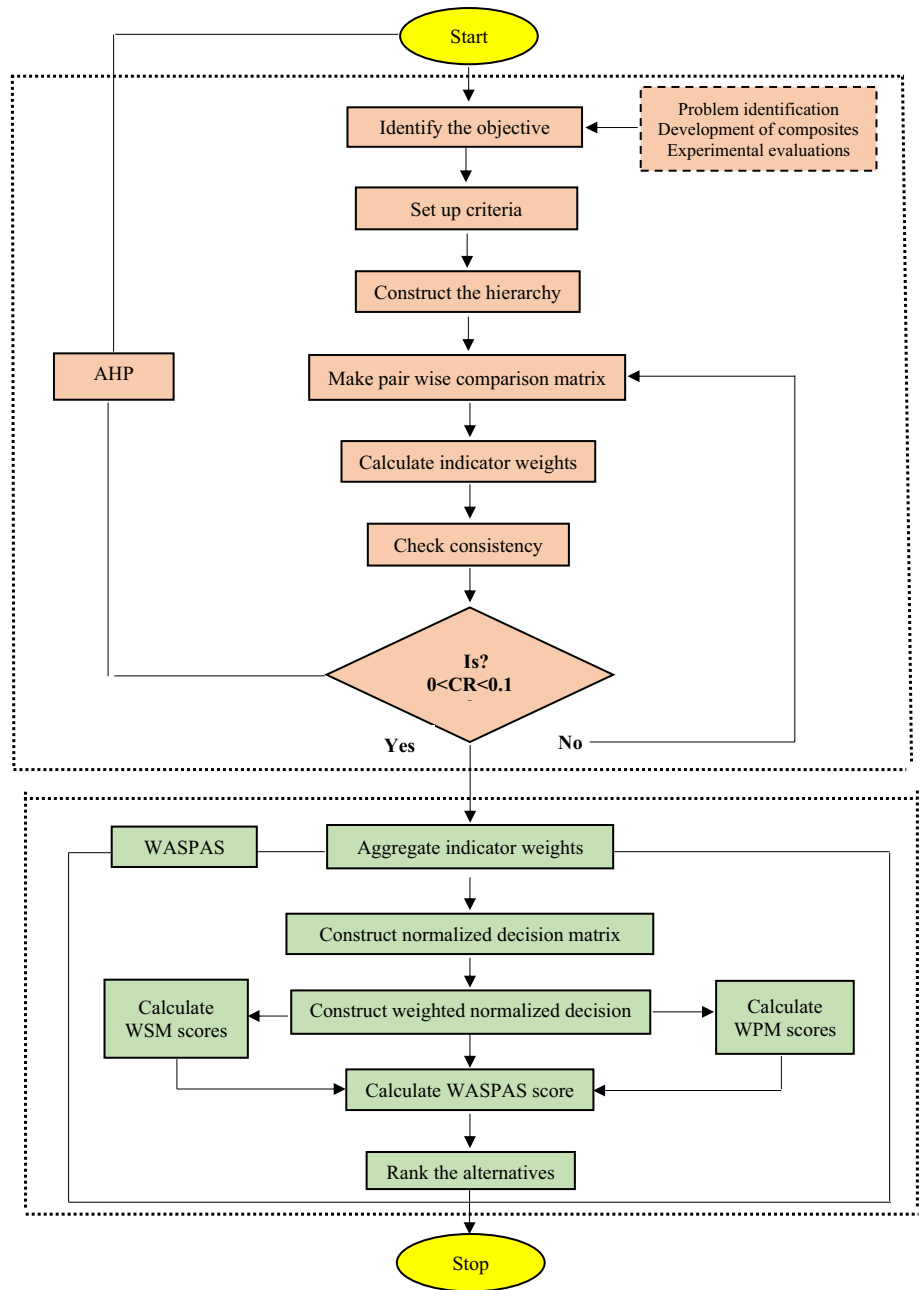


Table 5 Description of performance determining criteria (PDC)

PDCs	PDC	Description	Criteria type
C ₁	Abrasion wear	Removal of materials as debris	Cost criteria
C ₂	Water absorption	Moistures content of the composites	Cost criteria
C ₃	Density	Compactness of compositions	Beneficial criteria
C ₄	Flexural strength	Strength against the bending load	Beneficial criteria
C ₅	Compressive strength	Strength against the compressive load	Beneficial criteria

the alternatives is performed according to their performance score, and the results are summarized in Table 12.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{5.4416 - 5}{5 - 1} = 0.1104$$

Fig. 10 Hierarchy of material selection problem

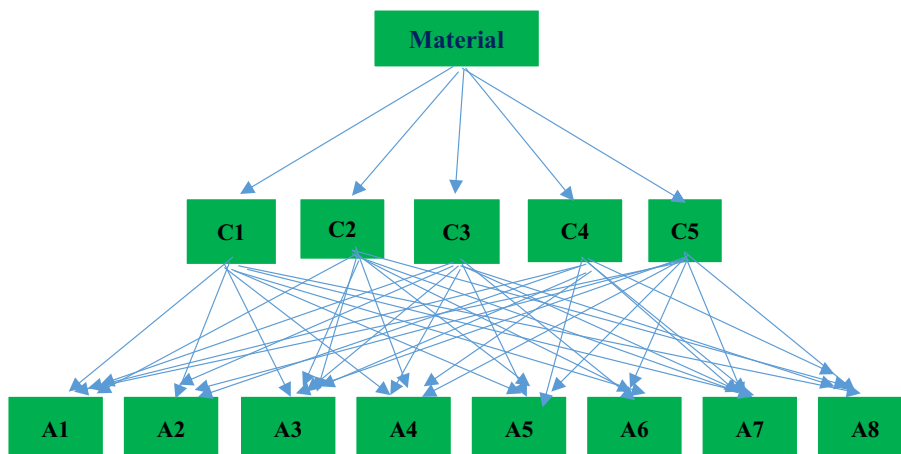


Table 6 Saaty's nine-point scale of relative importance

Relative importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

$$CR = \frac{CI}{RI} = \frac{0.1104}{1.12} = 0.0985 < 0.1$$

Results and discussion

The ranking of the alternatives obtained by using the proposed AHP-WASPAS model identifies the alternative A8 as the best alternative, whereas A1 is identified as the worst alternative. Moreover, the ranking sequence for the alternatives is found as A8 > A3 > A4 > A7 > A6 > A5 > A2 > A1.

Table 8 Random inconsistency (RI) indices

n	1	2	3	4	5
RI	0.00	0.00	0.58	0.9	1.12

Table 7 Pairwise comparison

	C1	C2	C3	C4	C5	GM	Weight
C1	1	5	1/5	1/7	1/7	0.4591	0.06
C2	1/5	1	1/7	1/8	1/9	0.2087	0.02
C3	5	7	1	1/3	1/3	1.3121	0.17
C4	7	8	3	1	1/3	2.2368	0.29
C5	7	9	3	3	1	3.5539	0.46

The higher strength offered by the PEEK, as compared to the other matrices, improves the workability of the composite PEEK70R15S15. Conversely, the poor strength of the LDPE is responsible for the decrease in the workability of LDPE70R15S15. The composite PEEK70R15S15 shows the optimum value for criterion C5, which is assigned a maximum weight and thus supports the results of the proposed AHP-WASPAS model with experimental investigations.

The advantages of the alternative A8 can be given as follows:

- The abrasive wear of the alternative A8 is found to be 0.05059 cm³ which shows a good wear resistance of the composites due to the sufficient amount of matrix with good strength to completely encapsulate the fillers particles at the given compositions.
- The water absorption of the alternative A8 is obtained to 0.0937% which indicates that the composite PEEK70R15S15 possesses fewer holes and porosity, as a result the composite possesses a low moisture content. Moreover, the value of water absorption is less than 5%; therefore, the composites can be satisfactorily used in ambient conditions.
- The alternative A8 results in a density of 1.5116 g/cm³, which shows the compositions, are held tightly which

Table 9 Decision matrix

S. No	Alternative	Abrasive wear (cm ³)	Water absorption (%)	Density (g/cm ³)	Flexural strength (MPa)	Compressive strength (MPa)
1	A1	0.04670	0.19960	1.07051	1.07269	7.5015
2	A2	0.17896	0.052383	1.67632	1.68477	8.5327
3	A3	0.07468	0.68434	1.33893	4.89543	24.7933
4	A4	0.03095	0.0397	1.6151	5.96	20.81
5	A5	0.06470	0.29960	1.7015	2.0276	15.467
6	A6	0.17698	0.082383	1.3626	4.9843	23.7241
7	A7	0.08647	0.86434	1.9833	3.8477	17.2741
8	A8	0.05059	0.0937	1.5116	6.564	32.7933
	$\sum x_{ij}^2$	0.086287	1.364892	19.32752	129.7249	3352.699
	$\sqrt{\sum x_{ij}^2}$	0.293746	1.168286	4.396307	11.38968	57.9025

Table 10 Normalized decision matrix

S. No	Alternative	Abrasive wear	Water absorption (%)	Density	Flexural strength	Compressive strength
1	A1	0.158981	0.170849	0.243502	0.094181	0.129554
2	A2	0.609233	0.044837	0.381302	0.147921	0.147363
3	A3	0.254233	0.585764	0.304558	0.429813	0.418191
4	A4	0.105363	0.033981	0.367377	0.523281	0.359397
5	A5	0.220258	0.256444	0.387029	0.178021	0.267121
6	A6	0.602492	0.070516	0.309942	0.174219	0.409725
7	A7	0.294369	0.739836	0.451129	0.341335	0.298331
8	A8	0.172223	0.080203	0.343834	0.576311	0.566354

Table 11 Weighted normalized decision matrix

S. No	Alternative	Abrasive wear	Water absorption (%)	Density	Flexural strength	Compressive strength
1	A1	0.009539	0.003417	0.041395	0.027312	0.059595
2	A2	0.036554	0.000897	0.064821	0.042897	0.067787
3	A3	0.015254	0.011715	0.051775	0.124646	0.196968
4	A4	0.006322	0.00068	0.062454	0.151751	0.165323
5	A5	0.013215	0.005129	0.065795	0.051626	0.122876
6	A6	0.03615	0.00141	0.05269	0.050524	0.188473
7	A7	0.017662	0.014797	0.076692	0.098987	0.137232
8	A8	0.010333	0.001604	0.058482	0.16713	0.260523

will offer good dimensional stability to the composites PEEK70R15S15 during application as floor tiles.

- The alternative A8 possess an optimum compressive strength and flexural strength of 32.7933 MPa and 6.564 MPa, respectively, which indicates a good response of the composites against an external compressive and bending load, respectively.

Comparisons of AHP-WASPAS results with MCDM techniques

The obtained rankings of the AHP-WASPAS are compared with other MCDM methods namely, WSM, TOPSIS, Complex Proportional Assessment (COPRAS), MOORA, Multi-Attributive Border Approximation area Comparison (MABAC) and Additive Ratio Assessment (ARAS). The ranking results are furnished in Table 13 and plotted in Fig. 11, which identifies the alternative A8

as the preferable alternative, whereas A1 is the least desirable by the considered MCDM techniques in this study. Moreover, a similar ranking sequence as $A_8 > A_3 > A_2$ is observed from the ranking of the considered MCDM methods in this study, except in the case of the MOORA method. The consistency of the results is verified by calculating the Spearman's Rank Correlation Coefficient

(SRCC) between the AHP-WASPAS and AHP-WSM, AHP-TOPSIS, AHP-COPRAS, AHP-MOORA, AHP-MABAC and AHP-ARAS by using the given Eq. 17. The results in values of SRCC are listed in Table 14 showing that the SRCC between the AHP-WASPAS, and AHP-WSM, AHP-MABAC and AHP-ARAS is 1; therefore, a similarity in the ranking sequences for AHP-WASPAS,

Table 12 Ranking of alternatives by AHP-WASPAS method

S. No	Alternatives	WSM Scores	WSM ranking	WPM Scores	WPM ranking	WASPAS score	WASPAS ranking
1	A1	0.14125	8	0.0000000219	8	0.070629226	8
2	A2	0.21295	7	0.0000000617	7	0.106478069	7
3	A3	0.40035	2	0.0000000227	2	0.200178816	2
4	A4	0.38652	3	0.0000000673	6	0.193264772	3
5	A5	0.25864	6	0.0000000282	4	0.129320638	6
6	A6	0.32924	5	0.0000000255	5	0.164623521	5
7	A7	0.34537	4	0.0000000272	1	0.172685213	4
8	A8	0.49804	1	0.0000000421	3	0.249021122	1

Table 13 Rankings of alternatives through the MCDM techniques

S. No	Alternatives	WSM	TOPSIS	COPRAS	MOORA	MABAC	ARAS
1	A ₁	8	8	8	8	8	8
2	A ₂	7	7	7	7	7	7
3	A ₃	2	2	2	3	2	2
4	A ₄	3	3	3	2	3	3
5	A ₅	6	6	5	6	6	6
6	A ₆	5	4	6	5	5	5
7	A ₇	4	5	4	4	4	4
8	A ₈	1	1	1	1	1	1

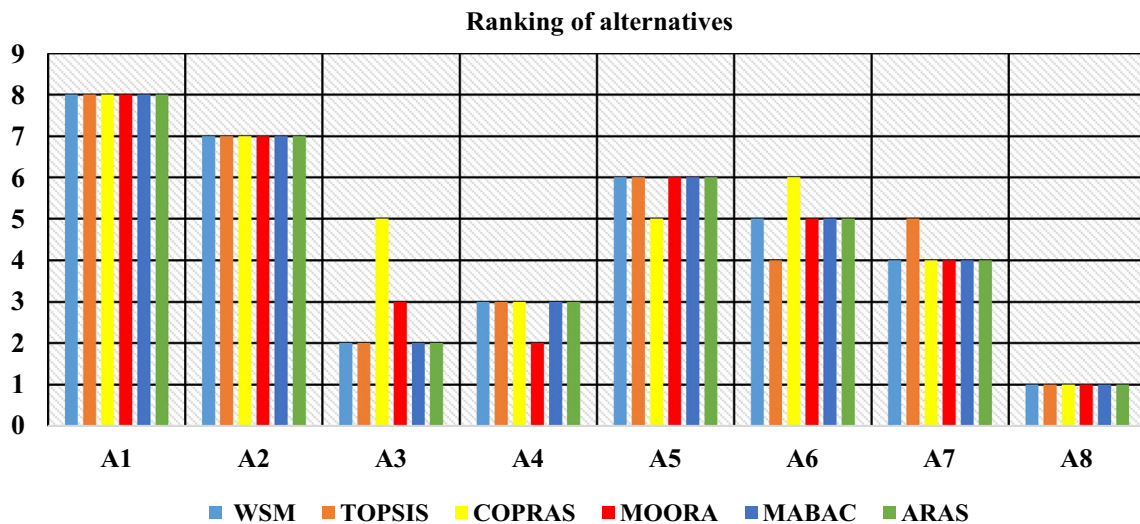


Fig. 11 Rankings of alternatives by the MCDM methods

Table 14 SRCC between AHP-WASPAS and MCDM techniques

	WASPAS	WSM	TOPSIS	COPRAS	MOORA	MABAC	ARAS
WASPAS	1	1	0.7857	0.7857	0.7857	1	1
WSM	–	1	0.7857	0.7857	0.7857	1	1
TOPSIS	–	–	1	0.3571	0.5714	0.7857	0.7857
COPRAS	–	–	–	1	0.5714	0.7857	0.7857
MOORA	–	–	–	–	1	0.7857	0.7857
MABAC	–	–	–	–	–	1	1
ARAS	–	–	–	–	–	–	1

AHP-WSM, AHP-MABAC and AHP-ARAS can be observed. Furthermore, the value SRCC for the AHP-WASPAS with AHP-TOPSIS, AHP-COPRAS, and AHP-MOORA is 0.7857; therefore, the rankings deviate slightly from the ranking of the proposed approach. Moreover, the plot for the SRCC in Fig. 12 reveals that the SRCC between the proposed method and other MCDMs is more than 0.7; therefore, the reliability of the proposed AHP-WASPAS model is verified.

$$SRCC = 1 - \frac{6 \sum_{i=1}^n d^2}{n^3 - n} \tag{17}$$

d = difference in the ranks. n = number of alternatives.

Sensitivity analysis (SA) of the rankings

In order to study the effect of parameters involved in the proposed AHP-WASPAS model, the SA is carried out for the different values for criteria weights and parameter λ in the AHP-WASPAS method. This section discusses in detail the ranking results obtained by performing the SA.

SA by varying the criteria weights

In order to understand the effect of the criteria weights in ranking, the SA is performed by considering the different cases for criteria weights as listed in Table 15. The plots for the ranking results for the considered cases of criteria weights are given in Fig. 13 revealing that the rankings are influenced by the change in criteria weights. The plot for the SA by considering the different cases for criteria weight given in Fig. 14 illustrates that for the considered cases of criteria weights the alternative A8 is recognized as the most suitable candidate, therefore establishes the robustness of the results for the best alternative.

SA by varying the parameter λ

The investigations for the effect of the parameter λ in the WASPAS method in ranking are conducted by considering the different cases for the parameter λ are given in Table 16, which shows that the rankings remain unchanged irrespective of the values of λ . Furthermore, the WASPAS scores for the considered cases of the parameter λ are furnished in Table 17 and plotted in Fig. 15, showing that WASPAS scores increase with the value of λ without affecting the overall ranking sequences. Therefore, the consistency of the results of the WASPAS technique is verified.

Fig. 12 SRCC between WASPAS and MCDM

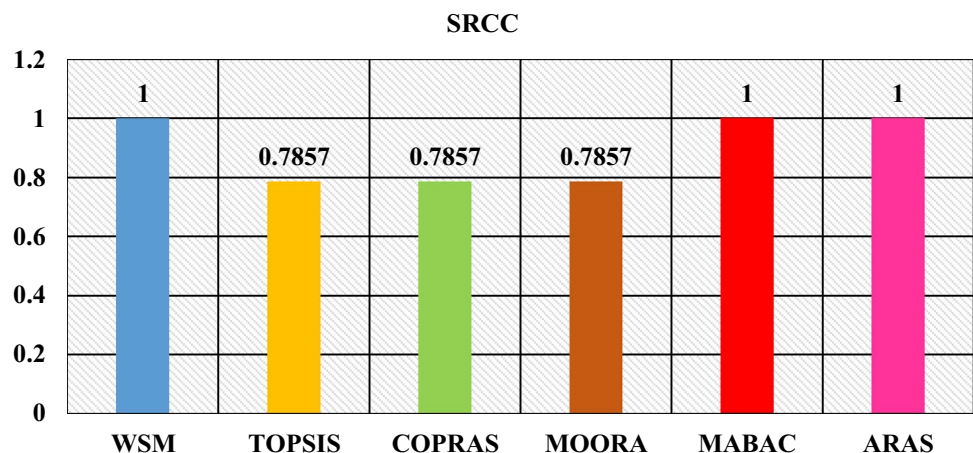


Table 15 Ranking of alternatives with criteria weights

Case No	Weights assigned	Ranking
1	Weights assigned to WASPAS	A8 > A3 > A4 > A7 > A6 > A5 > A2 > A1
2	Equal weight to each criterion	A7 > A3 > A8 > A6 > A4 > A2 > A5 > A1
3	50% to beneficial and 50% to non-beneficial	A7 > A3 > A6 > A8 > A2 > A5 > A4 > A1
4	60% to beneficial and 40% to non-beneficial	A7 > A3 > A8 > A6 > A4 > A2 > A5 > A1
5	70% to beneficial and 30% to non-beneficial	A7 > A3 > A8 > A4 > A6 > A5 > A2 > A1
6	80% to beneficial and 20% to non-beneficial	A8 > A7 > A3 > A4 > A6 > A5 > A2 > A1
7	90% to beneficial and 10% to non-beneficial	A7 > A3 > A6 > A8 > A2 > A5 > A4 > A1

Rankings of alternatives

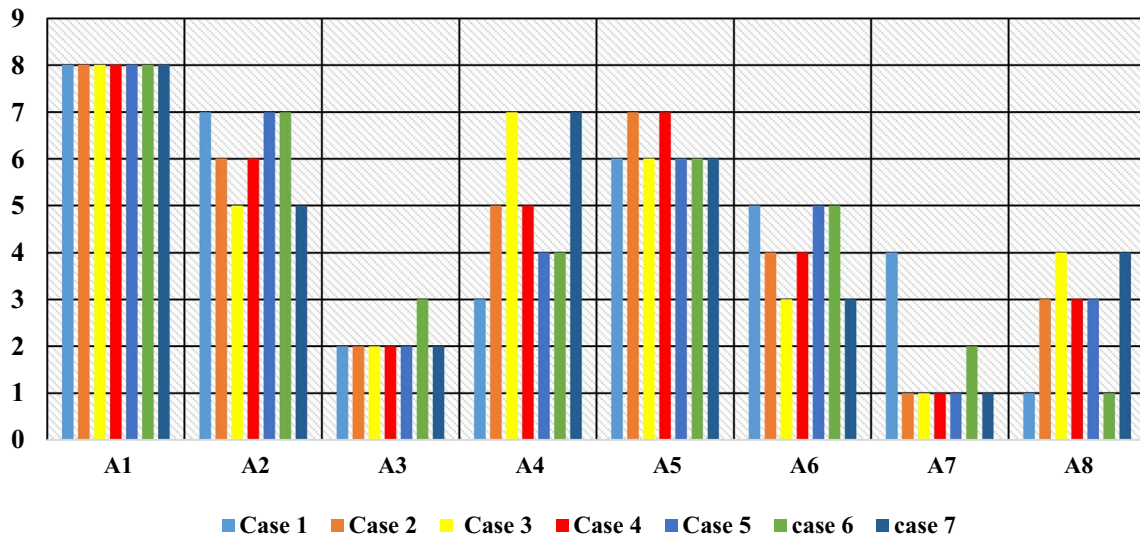


Fig. 13 Ranking of alternatives for the considered cases of criteria weights

SA for cases of criteria weight

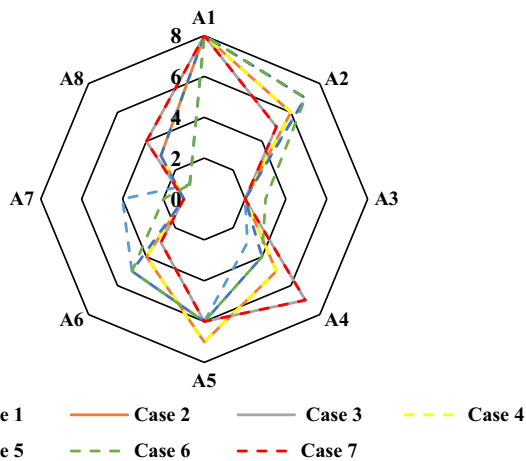


Fig. 14 SA for the considered cases of criteria weights

Table 16 Ranking of the alternatives for the values of λ

Case No.	λ	Ranking
1	0.1	A8 > A3 > A4 > A7 > A6 > A5 > A4 > A1
2	0.2	A8 > A3 > A4 > A7 > A6 > A5 > A4 > A1
3	0.3	A8 > A3 > A4 > A7 > A6 > A5 > A4 > A1
4	0.4	A8 > A3 > A4 > A7 > A6 > A5 > A4 > A1
5	0.5	A8 > A3 > A4 > A7 > A6 > A5 > A4 > A1
6	0.6	A8 > A3 > A4 > A7 > A6 > A5 > A4 > A1
7	0.7	A8 > A3 > A4 > A7 > A6 > A5 > A4 > A1
8	0.8	A8 > A3 > A4 > A7 > A6 > A5 > A4 > A1
9	0.9	A8 > A3 > A4 > A7 > A6 > A5 > A4 > A1

Table 17 WASPAS scores of alternatives for the values of λ

λ	A1	A2	A3	A4	A5	A6	A7	A8
0.1	0.0141	0.0212	0.04003	0.03865	0.02586	0.03292	0.03453	0.04980
0.2	0.02825	0.04259	0.08007	0.07730	0.05172	0.06584	0.06907	0.09960
0.3	0.04237	0.06388	0.12010	0.11595	0.07759	0.09877	0.10361	0.14941
0.4	0.05650	0.08518	0.16014	0.15461	0.10345	0.13169	0.13814	0.19921
0.5	0.07062	0.10647	0.20017	0.19326	0.12932	0.16462	0.17268	0.24902
0.6	0.08475	0.12777	0.24021	0.23191	0.15518	0.19754	0.20722	0.29882
0.7	0.09888	0.14906	0.28025	0.27057	0.18104	0.23047	0.24175	0.34862
0.8	0.11300	0.17036	0.32028	0.30922	0.20691	0.26339	0.27629	0.39843
0.9	0.12713	0.19166	0.36032	0.23277	0.29632	0.31083	0.31083	0.44823

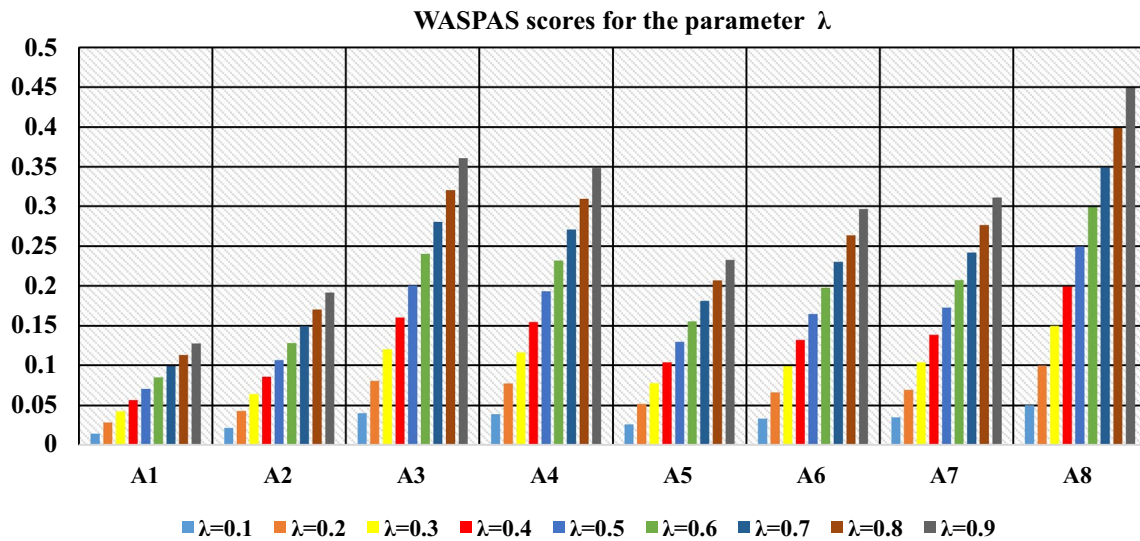


Fig. 15 WASPAS score for the parameter λ

Conclusions and future scope

In the era of the modern economy, plastics are widely used material in every sector; as a result, a huge amount of plastics wastes is inevitably produced from their uses. The circular economy sustainability trend is supported by the recycling of waste plastics. Therefore, the utilization of waste plastics in building construction is a sustainable and effective approach to the management of plastic waste. The environmental issues due to the mismanagement of plastic waste and the requirement of fresh raw materials for building construction can be successfully overcome by recycling plastic waste for the development of building construction materials. The proper selection of materials plays a decisive role in the successful development of a product. The wide varieties of materials with distinct features make the materials a tedious and cumbersome process. The practice of materials selection by trails and error methods consumes a lot of time and resources. Therefore, in spite of the immense potential of sustainable

polymer-based composites, progress is arrested due to the complexity involved in the materials selection process. The proposed AHP-WASPAS model could successfully deal with the issues of the material.

The silent conclusion drawn from the experimental results is given as follows:

- The different plastic wastes and rice husk ash can be successfully recycled in polymeric composites for structural applications. Moreover, the incorporation of sand particles enhances the performance of the composites.
- The performances of the composites are found satisfactory for their applications. However, an irregularity in the behaviour of the tested properties is observed. Therefore, increases the complexity of the material selection process.
- The proposed AHP-WASPAS model identified the recycled PEEK as the most suitable matrix, whereas LDPE is the least preferable matrix. Hence, the composite PEEK70R15S15 is considered the best composite for the development of floor tiles.

- The comparative analyses of the proposed AHP-WASPAS approach with other MCDM techniques observe a good similarity in the ranking results; therefore, the reliability of the proposed model is verified.
- The sensitivity analysis reveals that the rankings are influenced by the criteria weights; therefore, the consideration of the criteria weight plays a decisive role in the overall ranking results. Whereas the ranking result is unaffected by the change of parameter lambda (λ) in the WASPAS technique.

The study highlights the potential of waste plastics and agro-waste in sustainable composites for floor tiles. The research could mitigate the problem of environmental health arising due to the mismanagement of plastics and agro-wastes. The study has explored the workability of the sustainable composites developed by recycling waste plastics. The proposed AHP-WASPAS is a reliable technique for material selection in the design of sustainable composites. The study could support the researchers and industrialists working in the development of sustainable composites for diverse applications. Additionally, the research is beneficial for the decision and policymakers engaged in the domain of sustainability. The research could support in commercialization and large-scale production of sustainable composite materials for diverse applications.

The study has a limitation in composition and criteria. Moreover, the proposed model is incapable of handling the vagueness and uncertainty of the decision-makers. There are still ample opportunities for the recycling of different solid wastes for the development of composites. The research could be extended through the development of more samples by considering different fractions of plastics in replacement of fillers to further improve the performance of composites. The development of mathematical models for materials selection problems in fuzzy environments for different mixture proportions and characterizations by considering the other attributes with different MCDM techniques and sensitivity analysis for the parameters involved can be considered as a future scope of the present research.

Author contributions All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. AS conceptualization, experimentation, and writing of the manuscript. PKD supervised, provided resources, and facilities for this work. SK helped in experimentation.

Data Availability All data generated or analysed during this study are included in this published article.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This statement is to certify that all authors have seen and approved the manuscript being submitted. We warrant that the article is the author's original work. We warrant that the article has not received prior publication and is not under consideration for publication elsewhere. On behalf of co-authors, the corresponding author shall bear full responsibility for the submission.

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